Introduction

One of the improvements necessary to meet the Collider Run II performance goals is to improve the performance of the antiproton collection lens by increasing the magnetic field gradient from 750 Tesla per meter to 1000 Tesla per meter or higher.

A history of Fermilab solid lens service performance is provided below in Table 1. A more detailed summary is given in Attachment 1. Improvements have been made in solid lens performance, primarily in external cooling water lines, the totality of which becomes apparent starting with lens 16. Early lens failures were due to external water leaks which were detected by cooling water system pressure and water level alarms. These early lenses could continue to be operated by periodic additions of cooling water to the cooling water systems and/or repairs to the cooling water lines. Eventually, the water leaks grew until continued operation was impractical. Starting with lens 16, the common failure mode in lenses with operating history shifts from external water leaks to internal water to lithium barrier failures (septum breach). The symptoms of the septum breach failures include high conductivity and high pH in the lens cooling water system which leads to an immediate end to the usefulness of the lens.

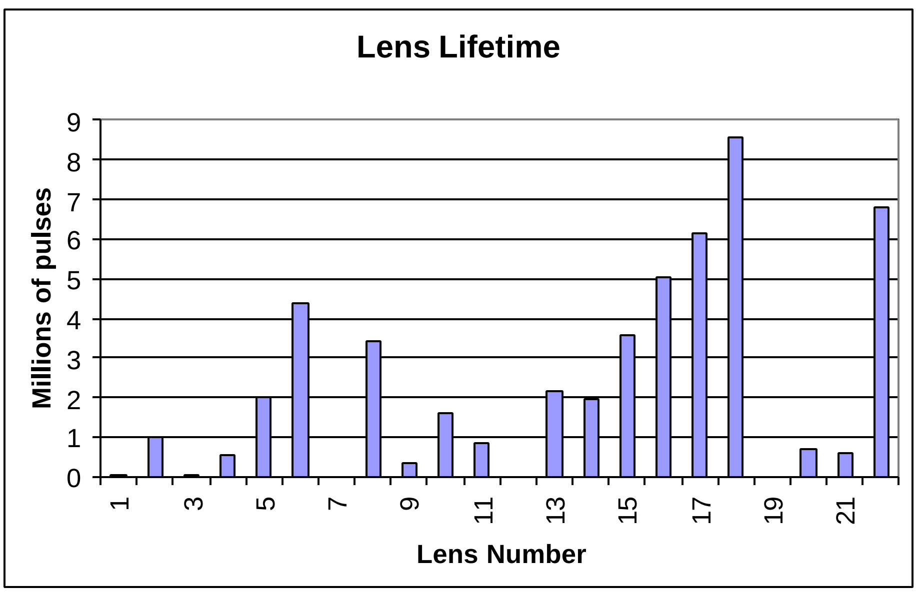

Figure 1

Many facets of lens construction and operation are being considered at this time with the goal of improving lens performance including lens assembly procedures, the lens fill procedure, lens test stand operation, choice of lithium isotope enrichment, helium and hydrogen gas production during operation, and more. It would be useful to disassemble failed operational lenses such as lenses 16, 17, 18, 20, and 21 to examine the septum breaches. An understanding of the location of the breaches along with metallurgical examinations of them may lead to an understanding of the cause of failures which may lead to development of an engineering solution. The purpose of this note is to describe a method of lithium removal so that examination of failed radioactive lenses may be pursued.

Removal of the lithium presents an opportunity to make a measurement of radioisotope production due to beam interaction with lithium. The quantities of radioisotopes produced in a lithium lens as a function of beam intensity was predicted [1]. A measurement has been made on the production of tritium and beryllium 7 on lithium in the target vault environment [2]. The results of the calculation and measurement may be used to predict the quantities of radioisotopes which may be present in lenses we propose to disassemble. Since all the lenses have been out of service for a minimum of 5 years, at least 33 half lives of beryllium 7 have passed so beryllium 7 may be neglected entirely. The anticipated quantities of tritium, neglecting radioactive decay by a half life of 12.3 years, as a function of failed operational lens is shown in Table 2.

Lens number	Removed from service	Total beam pulses	Average intensity per pulse	Total beam intensity (protons)	Tritium inventory (Ci) [ref 1]	Tritium inventory (Ci) [ref 2]
16	10/92	3,200,000	2E12	6.4E18	4	0.9
17	3/93	5,146,131	2E12	1E19	6.25	1.4

18	4/94	7,870,738	2E12	1.6E19	10	2.3
21	6/95	299,000	3E12	9E17	0.56	0.13
22	11/95	194,484	3E12	6E17	0.38	0.09

Table 2

Since lens 22 has been exposed to the lowest integrated intensity, it would be prudent to examine it first. In the course of the examination, tritium measurements would be made for comparison with the results of reference 1 and 2. It is very likely that any tritium produced in gaseous form in the lithium contour during beam operation escaped into the target vault through the water system when the lithium containment failed. The quantities of tritium which remain are thought to be due either to trapped interstitial gas or as a compound such as lithium hydride. The presence of the former is considered unlikely because of the diffusive nature of hydrogen gas. The compound LiH (MW 7.95, ρ 0.82, mp 680°C), forms readily when Li is exposed to hydrogen at elevated temperatures. LiH reacts readily in water to produce hydrogen and LiOH. One may speculate that the effect of relatively intense ionization and elevated temperature which occurs during the beam and current pulse may encourage the formation of LiH. Like Li metal, LiH is also reactive in water and produces hydrogen gas [ref 3].

Discussion

Lithium removal from a lens body will be accomplished in three phases.

In phase 1, the lithium lens body is placed in a glove box and an Argon atmosphere is established. Attachment 2 shows a cross section of a typical lens body. The total lithium volume contained by the lens body is approximately 100 cc. Complete removal of lithium by melting will not be possible because lithium wets the titanium and steel body surfaces. It is assumed that 90% of the lithium metal is to be removed by melting in phase 1. The lens body fill ports are opened and the lens body is heated to 200 °C. Argon gas pressure is used to flow lithium out of the lens body into a ceramic dish where it is cooled. Tritium concentrations in the resulting Argon purge gas are monitored with a tritium gas detector (Triton) during release. When lithium metal flow stops from the initial purge, the drain and purge operation is reversed to remove lithium metal from the low point at the opposite end of the lens body. Upon completion of lithium metal draining, lens body heating is discontinued while the argon gas purge continues to ensure a complete flow path through the lens body exists. Lithium removed from the lens body is weighed and an estimate of remaining lithium in the lens body is made. Lithium metal is placed in mineral oil in a suitable storage container.

In phase 2, it is assumed that 10% of the original lithium metal volume remains in the lens body. The argon atmosphere established in phase 1 continues without interruption. A tubing pump is connected to the lens body along with a hydrogen gas collection system. Deionized, deoxygenated water (pbar LCW) is used in the hydrogen gas collection system which basically consists of a Bell jar with appropriate plumbing. The phase 2 system is established in a way such that no oxygen is introduced into the collection system or glove box. Water is introduced into the lens body via the tubing pump. Hydrogen gas and LiOH solution are pumped/released into the Bell jar. The quantity of water introduced into the lens body is carefully controlled to limit the hydrogen production rate. The Bell jar is sized to accommodate at least twice the volume of hydrogen anticipated to be liberated in the water/lithium reaction.

The volume of water contained by the hydrogen gas collection system is estimated to be 20 times that required to react remaining lithium metal. The estimate is based upon the assumption that the Li reaction will occur with water until at least a saturated solution of LiOH is produced. When the lithium/water reaction appears to be complete, the lens body with be flushed with a quantity of fresh deoxygenated, DI water. A soak period will be observed to allow addition lithium water reaction. Then the pH of the soak water will be checked. When the pH of the soak water is found to be below 9 to 10, the lithium metal can be considered to be completely consumed. The lens body can then be drained. A combination of lens body heating and an Argon purge can be used to dry out the lens body. Finally, the lens body can be removed from the Argon atmosphere controlled glove box.

In phase 3, the hydrogen collection from the lithium water reaction in phase 2 is burned completely. The resulting water vapor is collected and is analyzed for tritium. The argon atmosphere in the glove box is replaced by air. A propane fueled Bunsen burner is used as flame source to burn hydrogen. The hydrogen is slowly and carefully introduced into the propane fueled flame. The resulting water vapor is drawn up into a heated copper chimney to prevent condensation. Heated water vapor is introduced into a water cooled Graham condenser where water from the combustion of propane and hydrogen is condensed. The water is collected at the exit of the condenser in an Erlenmeyer flask. The Erlenmeyer flask is of the filtration type and contains a side arm through which air is pumped to ensure positive flow of combustion gas and water vapor throughout the system. The air pump may be either a motor driven vane type or a water driven filtration type depending of the efficacy and flow requirement to ensure water vapor transport through the copper chimney.

In phase 4, system disassembly and handling of LiOH solution is addressed.

References

1. Radiological Consequences of a Lithium Lens Rupture, pbar Note 454 , W. S. Freeman, 3/3/86

2. Lithium Irradiation Experiment, pbar Note 640, A. Leveling, 8/22/00

3. Rare Metals Handbook, Chapter 12, Lithium, P.E. Landolt

Phase 1 Procedure

Refer to Attachment 3 for Phase 1 procedural steps.

1. Attach individual purge and drain line arm assemblies to the lens body fill ports.

2. Mount lens body in insulated fixture with the beam axis aligned horizontally and with the fill ports positioned down.

3. Install lens body fixture, phase 1 components, and phase 2 components (without water) into the glove box.

4. Establish an argon atmosphere in the glove box.

5. Connect the glove box vent to the gas inlet of the Triton tritium gas sampler. The exhaust of the Triton should be routed to an outdoor location.

6. Ensure Triton gas sampler is operational and connected to an appropriate data logging system (e.g., ACNET).

7. Open the lens body fill ports.

8. Open the argon purge port 1 and lens body drain port 1.

9. Heat the lens body to approximately 200 *C.

10. Apply a 10psig argon gas pressure on purge port 1.

    NOTE: Introduction of Argon purge gas to the lens body will cause argon gas to flow through the vent of the glove box.

11. Monitor Triton response throughout the Argon purge

12. Collect liquid lithium into a 0.5 liter ceramic dish from drain port 1.

NOTE: Some provision for measuring the mass or volume of lithium removed should be used so that an estimate of the lithium remaining in the lens body may be made.

NOTE: Preheating the gas may be desirable to prevent lithium freezing in the lens body.

13. When lithium ceases to flow from the lens body, stop argon gas flow.

    CAUTION: The lens body is hot and should be handled with insulted tools and/or gloves.

14. Open drain port 2 and argon purge port 2.

15. Close argon purge port 1 and drain port 1.

16. Continue heating.

17. Reapply 10 psig argon gas pressure to vent line to aid in lithium removal.

18. Collect liquid lithium in ceramic dish from drain port 2.

19. When lithium no longer flows from lens body, turn off lens body heaters.

20. Continue argon gas flow to aid in body cooling and to ensure flow path exists through the lens body.

NOTE: Argon gas flow may be arrested by lithium metal freezing in the purge pathway. If this occurs, energize lens body heaters and repeat steps 14 through 18 until argon gas flow is established in cooled lens body.

21. Note the mass Li metal collected in the ceramic dish and estimate the volume of lithium remaining in the lens body.

22. Transfer solid, cool Li metal to an appropriate covered, mineral oil-filled container for storage.

23. Transfer lithium metal out of glove box and place into storage cabinet.

24. When lens body has cooled to room temperature, discontinue argon gas flow through the lens body.

25. Shut drain port #2 and purge port #2.

26. Allow Triton gas monitor to continue to operate until background counting rate returns.

27. Calculate the quantity of tritium released.

Phase 2 Procedure

Refer to Attachment 4 for Phase 2 procedure setup.

1. Maintain Argon atmosphere in glove box throughout Phase 2 procedure.

   CAUTION: Prepurge all tubing with Argon gas prior to connecting to the tubing pump or gas collection system.

2. Reposition the lens body in holding fixture with fill arm fixtures toward the top.

3. Add deionized, deoxygenated water to the Bell jar and ensure a water seal is provided by the external tank.

4. Connect tubing pump and hydrogen gas collection system to the lens body.

   CAUTION: The water system is vented into a Bell jar so that hydrogen gas pressure will not build up and blow water line connections from the circulating water system.

   NOTE: The total water volume required to circulate through the lens body is based upon the amount of lithium remaining in the lens body. For example, 1 liter of water should be sufficient to react 10 cc of lithium in the lens body and provide sufficient cooling. Since the total circulating water volume is approximately 5 gallons, the resulting LiOH solution should not be saturated thereby preventing obstruction of the water path by precipitates of LiOH. Approximately 41 kcal heat is produced and assuming no heat transfer to the lens body would raise the temperature of 1 liter of water 41 degrees C.

Caution: Assuming 10 cc of lithium metal remain in the lens body, 8 to 9 liters of H2 gas with be produced due to the water reaction with lithium metal. This gas is to be stored in the Bell jar for use in phase 3.

Caution: In steps 4 through 12, hydrogen gas will be produced and collected in the Bell Jar. If at any time, the production of gas becomes excessive, discontinue operation of the tubing pump and allow the hydrogen gas production to subside before proceeding.

NOTE: the water pH will increase from 7 to 14 as potentially radioactive lithium metal reacts with circulating water. Use appropriate precautions when handling caustic, potentially radioactive solutions.

5. Open lens body drain port #1 and #2.

6. Introduce 10 milliliters of water into the lens body with tubing pump

7. Note release of hydrogen gas from lens body by formation of gas bubbles in Bell jar. Note time of introduction of water.

8. When evidence of gas production subsides as indicated by flow meter, note time

9. Introduce 10 milliliters of water into the lens body with tubing pump.

10. Repeat steps 7 through 9 until 100 milliliters of water have been added.

11. Calculate the average of times recorded in step 8.

12. Establish a flow rate of 10 milliliter per average time found in step 9 through the pump body with the tubing pump for a time equal to 20 times the average time found in steps 5 through 8.

13. Continuously monitor discharge tube in Bell Jar to monitor gas production.

14. Establish a 50 milliliter per minute flow rate through the lens body for 1.5 hours or until evidence of hydrogen gas production subsides.

15. Stop tubing pump.

16. Close pinch clamps in pumping circuit.

17. Disconnect supply side of pump from Bell jar reservoir and connect to a fresh supply of deoxygenated, deionized water.

18. Open pinch clamps in pumping circuit.

19. Pump 2 liters of clean DI water into the lens body and allow to discharge into Bell jar reservoir.

20. Stop tubing pump. Monitor discharge tubing for evidence of hydrogen production for 5 minutes.

21. If there is evidence of hydrogen gas production reconnect tubing pump to Bell jar reservoir and proceed to step 14.

22. If there is no evidence of hydrogen gas production, proceed to step 23.

23. Collect a 50 milliliter sample of water by momentarily energizing tubing pump and collecting the effluent in a beaker.

24. Check pH of sample and record the value.

25. If the pH exceeds 9, reconnect tubing pump to lens body and Bell jar and proceed to step 14.

26. If pH of sample is less than 9, assume that all lithium has been reacted and proceed to step 27.

27. Shut lens body drain ports #1 and #2.

28. Rotate lens body in fixture so that fill arms are oriented downward.

29. Open drain ports #1 and #2.

30. Disconnect pump suction from Bell jar and direct discharge to Bell jar.

31. Energize pump to push remaining water out of lens body with Argon.

32. Stop pump.

33. Install Mohr pinch clamp on Bell Jar vent line to maintain gas volume.

34. Disconnect discharge line from lens body to Bell Jar vent line.

35. Reverse pump direction and direct pump suction to Bell jar.

36. Energize pump to remove water from low point.

37. Stop pump

38. Close drain ports #1 and #2.

39. Remove lens body from glovebox.

Phase 3 Procedure

Refer to Attachment 5 for phase 3 procedure.

1. Ensure pinch clamps are closed on Bell jar tubing to preserve hydrogen gas collected in the Bell jar.

2. Establish an air atmosphere in the glove box.

3. Setup burner, chimney, and condenser as shown in Attachment 5.

4. Establish cooling water flow to Graham condenser.

5. Establish air flow through chimney by energizing air pump or water filtration pump.

6. Light propane fueled Bunsen burner and establish a flame height of 1 inch by adjusting fuel inlet needle valve and air mixing sleeve.

    Caution, the glass funnel and chimney will become very hot due to burner operation. Do not handle the glass funnel or chimney until after the burner gas flow has been stopped and these components have been permitted to cool.

7. Allow burner to operate for 5 minutes and note collection of water in Erlenmeyer flask.

8. Remove pinch clamp from Bell jar vent.

9. Carefully introduce hydrogen gas into Bunsen burner flame by adding water to the Bell jar reservoir using the tubing pump

10. Continue introduction of hydrogen gas into Bunsen burner flame until all gas in the Bell jar is consumed and water just reaches check valve in the vent line.

11. Install pinch clamp on Bell jar vent.

12. Stop gas flow to Bunsen burner and ensure flame is extinguished.

13. Allow chimney and funnel to cool. Collect water in Erlenmeyer flash for further analysis.

Phase 4 Procedure

1. Neutralize LiOH solution with HCl to pH range of 5 to 9.

   NOTE: Assuming 10cc of lithium metal are removing by reacting with water, approximately 150 ml of 5 N HCl will be required.

2. Collect samples of neutralized solution for analysis of tritium and accelerator produced isotopes.

   NOTE: Water used to dissolve lithium may need to be disposed of as radioactive waste depending up sample results obtained from step 21.

   NOTE: Other lithium compounds may be present and fixed at the site of the breach. Removal of such materials should be made in a passive manner so that septum surfaces are not altered by this removal.

3. Pump neutralized LiOH solution from Bell jar reservoir to 5 gallon plastic carboy and dispose of in accordance with laboratory procedures.

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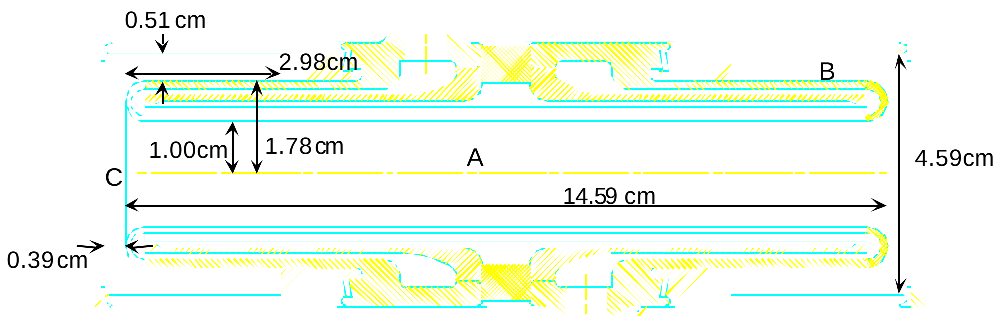


NOTE: Assume fill ports are negligible

Volume calculation

Volume A = $\pi r^2 l$
r = 1 cm
l = 14.59 cm

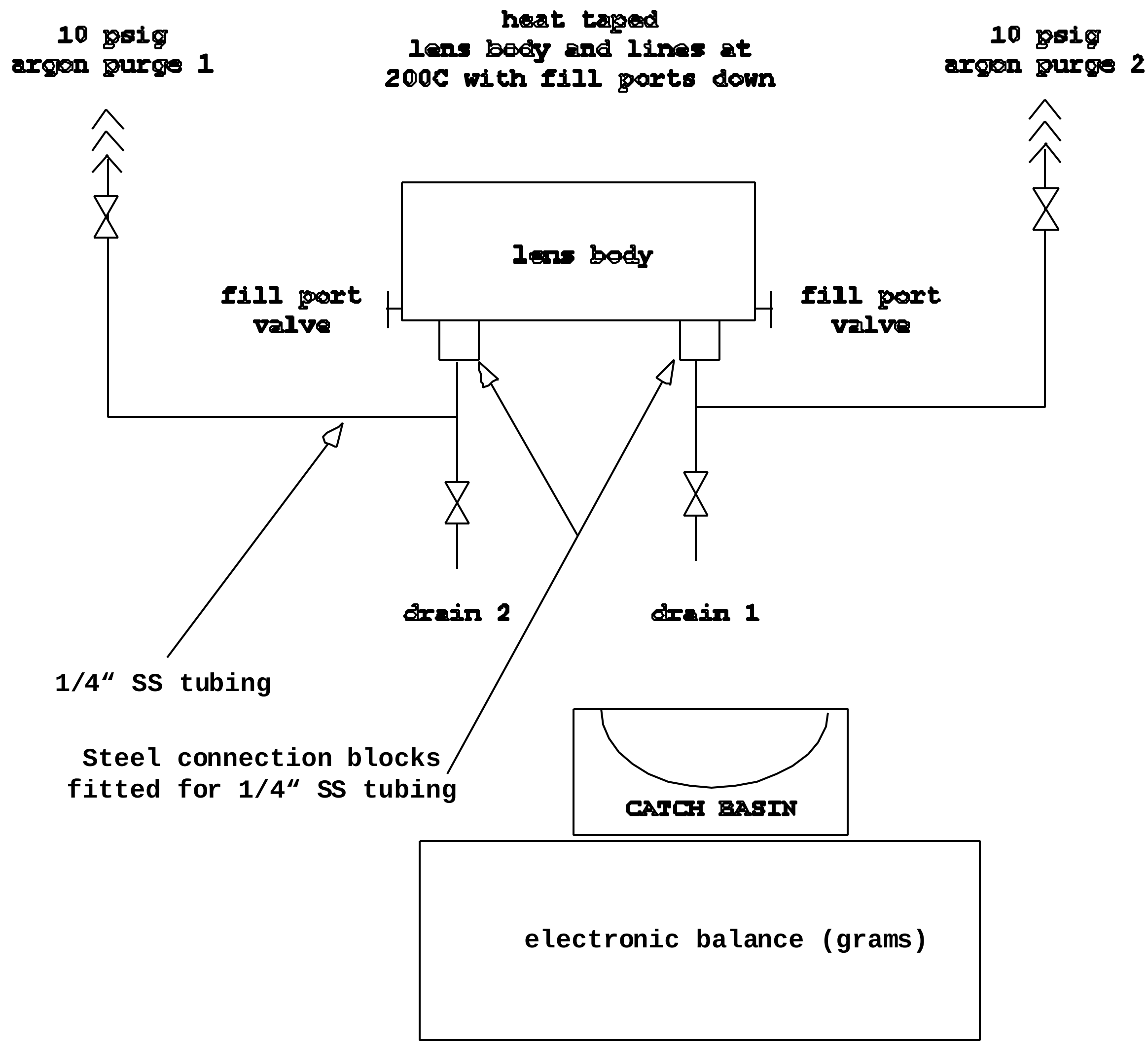
Volume B = $2\pi(d/2^2 - r^2)l$
d = 4.59 cm
r = 1.78 cm
l = 2.98 cm

Volume C = $2\pi(d/2)^2 l$
d = 4.59 cm
l = 0.39 cm

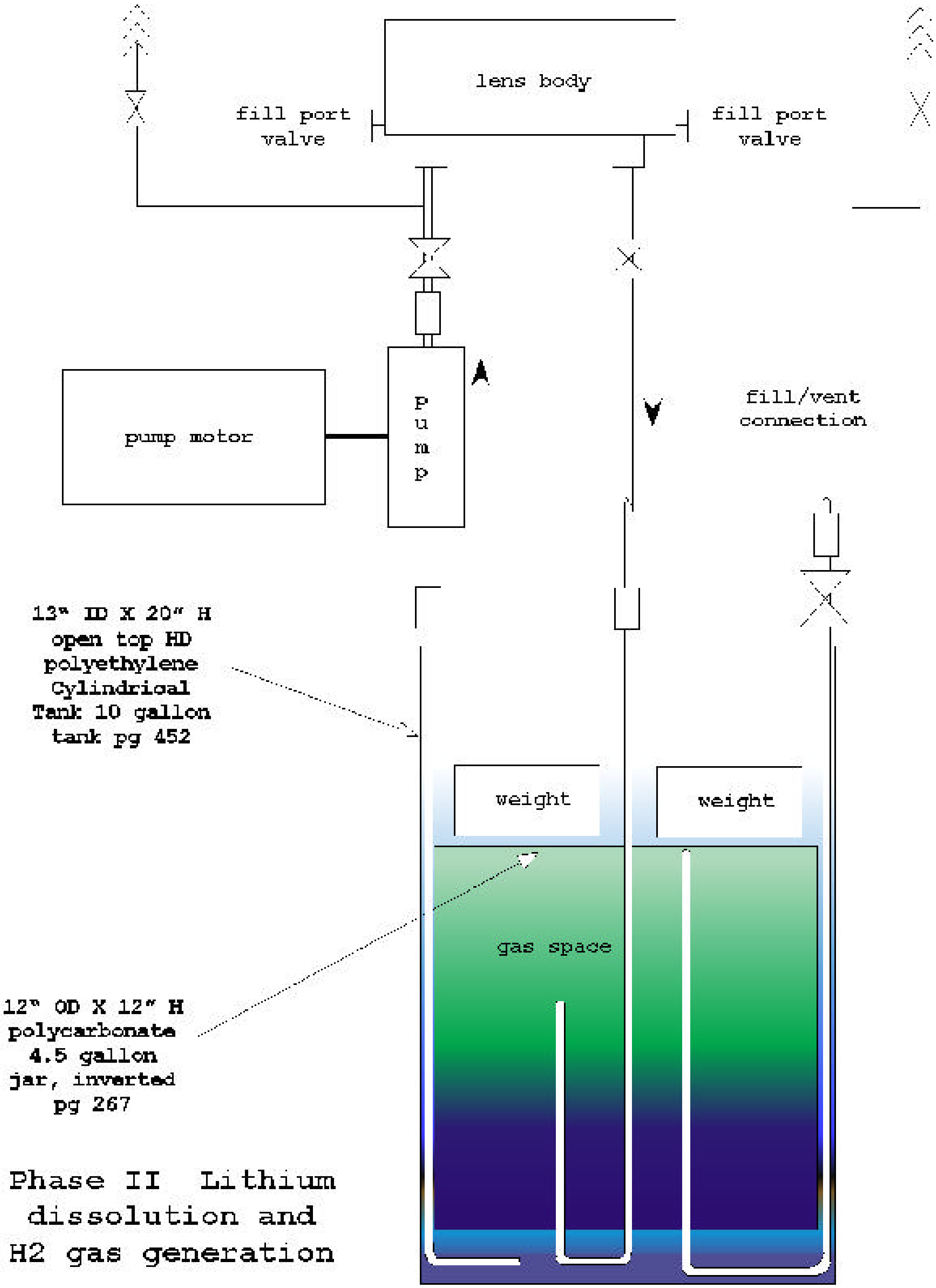
Total Volume = A + B + C = 98cc

Attachment 2

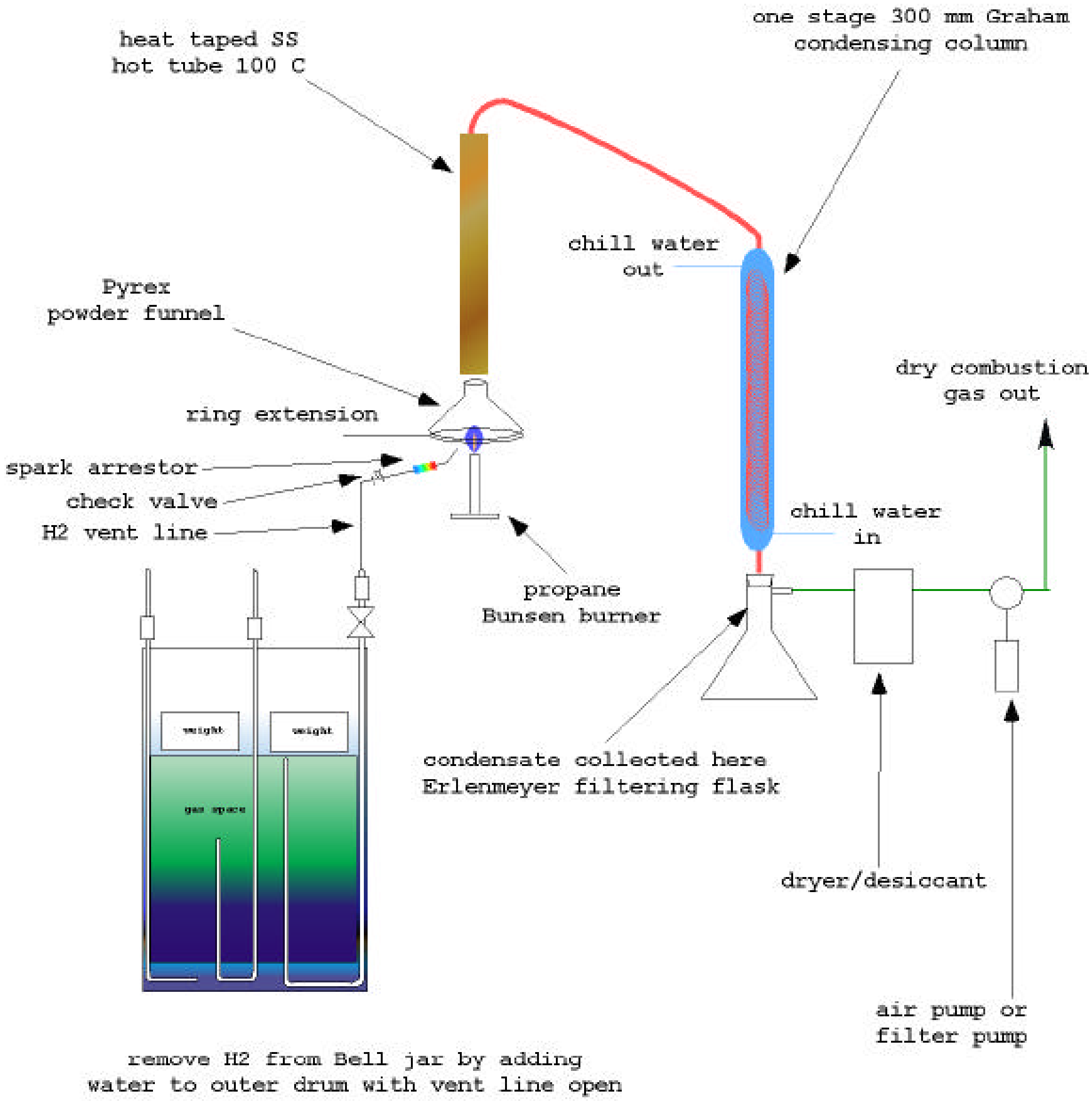
prepared by T. Leveling
6/26/00



Phase I
Lens Body Lithium Draining



Phase II Lithium dissolution and H2 gas generation



Collection Lens Body Unfilling Plan
PHASE III